Making the Most of DOCSIS OFDMA

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Thursday, Feb. 18, 2021

11:00 am –12:00 pm ET (8::00 am --9:00 am PT)

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Today’s Speakers

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Agenda

- **Light Reading—**DOCSIS 3.1 & OFDMA Overview
- **Vecima—**DOCSIS Upstream Growth with OFDMA
- **Cisco—**OFDMA Characteristics, Benefits & Trials
- **VIAVI Solutions—**OFDMA & the Path to 1 Gig
- **Red Hat**—DOCSIS & Software-Defined Architectures
- **SCTE**—Training, Standards, Certifications & Events
- **Audience Q&A**

Larger NA MSOs Have Mostly Rolled Out DOCSIS 3.1

MSOs	Deployments
Comcast	Now offers DOCSIS 3.1 to virtually whole footprint after completing rollout in Oct. 2018.
Charter Communications	Now offers D3.1 to over 95% of its footprint; aimed to wrap up rollout by end of 2018.
Cox Communications	Offers D3.1 to well over 50% of its footprint; planned to reach 99% coverage by end of 2019.
Altice USA	Despite plans to build FTTH networks, now quietly rolling out D3.1 in New York area
Mediacom Communications	One of the first MSOs to deploy D3.1, it now offers service to virtually all its footprint
Shaw Communications	Now offers D3.1 service to virtually all its Canadian homes, using Comcast's Xb6 modems.
Midco	Another early D3.1 adopter, it now offers service to over 90% of its footprint
WOW	Has now rolled out D3.1 to at least 95% of its footprint
Rogers Communications	Now offers D3.1 service to virtually all its Canadian homes, using Comcast's Xb6 modems.
Cable One	Now offers 1-Gig service to 95% of footprint; but relying solely on D3.0, not D3.1.
RCN	Offers D3.1 in all legacy markets; now upgrading former Wave Broadband markets
Atlantic Broadband	Has rolled out DOCSIS 3.1 to over 90% of its footprint
BCI	Now offers D3.1 to 99.9% of homes in footprint.
Videotron	Has broadly deployed DOCSIS 3.1 throughout its Quebec markets.
Cogeco Connexion	Now offers D3.1 service Has to over 60% of its Ontario & Quebec homes.

While DOCSIS 3.1 Era Also Well Underway in Europe

MSO	Deployments
Liberty Global	Plans to offer DOCSIS 3.1 service to its nearly 15 million UK homes by the end of 2021, after starting with Southampton and Manchester launches in fall 2019.
Vodafone	Launched D3.1 in four Bavarian cities in fall 2018, covering 400,000 homes. Aimed to offer service to 13 million German homes by the end of 2020.
Com Hem (Tele2)	Has upgraded most of its HFC network in Sweden for D3.1, with many small sites left.
Stofa	Has now deployed D3.1 & DAA to 60% to 65% of its 400,000-home network in Denmark, with plans to reach 90% to 95% coverage by spring 2021.
TDC	Planned to complete rollout of D3.1 in Denmark by the end of 2018.
NOS	Has completed full network upgrade to D3.1 in Portugal and developed D3.1 routers.
Telenet	Started rolling out D3.1 service in Belgium in Sept. 2019.
Eltrona	Launched D3.1 service in Luxembourg in September 2018.
Melita	Completed upgrading its Malta network to D3.1 in April 2019.

Impact of COVID-19 on Broadband – US Cable Networks

National Peak Internet Growth During COVID-19

Observed Increase in Peak Consumer Usage Since Early March 2020

Overall change in pre-COVID internet usage since 3/1/20

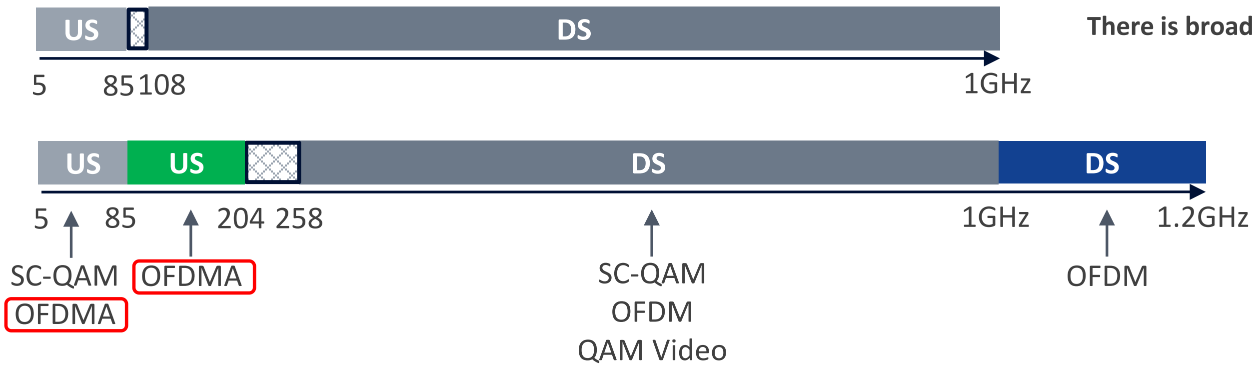
Source: Data from NCTA member companies and others.

So What is OFDMA?

In OFDM, subcarrier orthogonality is achieved by spacing the subcarriers at the reciprocal of the symbol period (T), also called symbol duration time. This spacing results in the sinc (sin x/x) frequency response curves of the subcarriers lining up so that the peak of one subcarrier's response curve falls on the first nulls of the lower and upper adjacent subcarriers' response curves. Orthogonal subcarriers each have exactly an integer number of cycles in the interval T.

Orthogonal Frequency Division Multiple Access (OFDMA)
An OFDM-based multiple-access scheme in which different subcarriers or groups of subcarriers are assigned to different users.

LIFE WITH OFDMA



There is broad interest in moving to high split in coming years.

▸ Addition of OFDMA to Mid-Split and move to High-Split boosts upstream capacity.

US Split MHz	MHz OFDMA	QAM Mod	US MAC Rate
85	80	1024	616 Mbps
204	192	1024 up to 108 MHz; 4096 above that	1.62 Gbps

Numbers show best case CMTS throughputs, assuming no upstream OOB and fully usable spectrum at 1K+ QAM.

Full OFDMA is nearly 2x the upstream capacity of full SC-QAM. Reality is a mixture somewhere in the middle.

What's New with DOCSIS 4.0

- **ESD**: New top end for cable plant – 1,794 MHz – more spectrum, more speed
- **FDD:** Provides new upstream/downstream frequency splits above High-Split, referred to as Ultra High-Splits at 300, 396, 492, and 684 MHz
- New diplex filters for more upstream (flexible choices)
- SCTE working groups for 1.8 GHz and 3.0 GHz
- Other Considerations
  - Distributed CMTS Architecture
  - Point of Entry Modem for extended spectrum applications of ESD.
- But foundation for DOCSIS 4.0 is the same DOCSIS 3.1 technology
  - Orthogonal Frequency Division Multiplexing (OFDM)
  - Orthogonal Frequency Division Multiple Access (OFDMA)

Rex Coldren

Principal Access Architect, Office of the CTO

Vecima

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DOCSIS Upstream Growth with OFDMA

February 18, 2021

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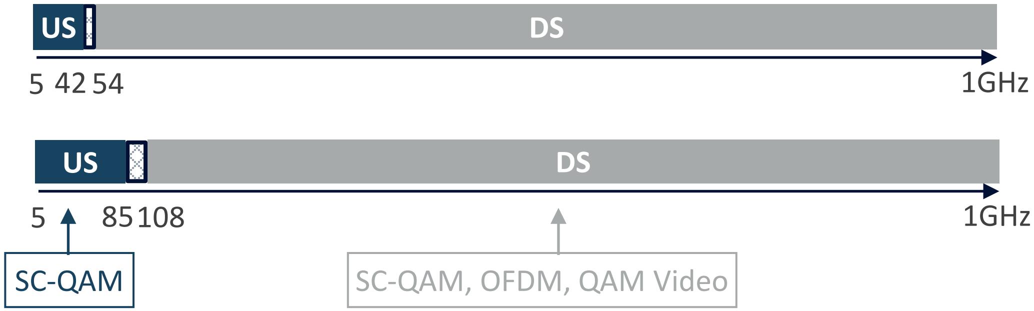
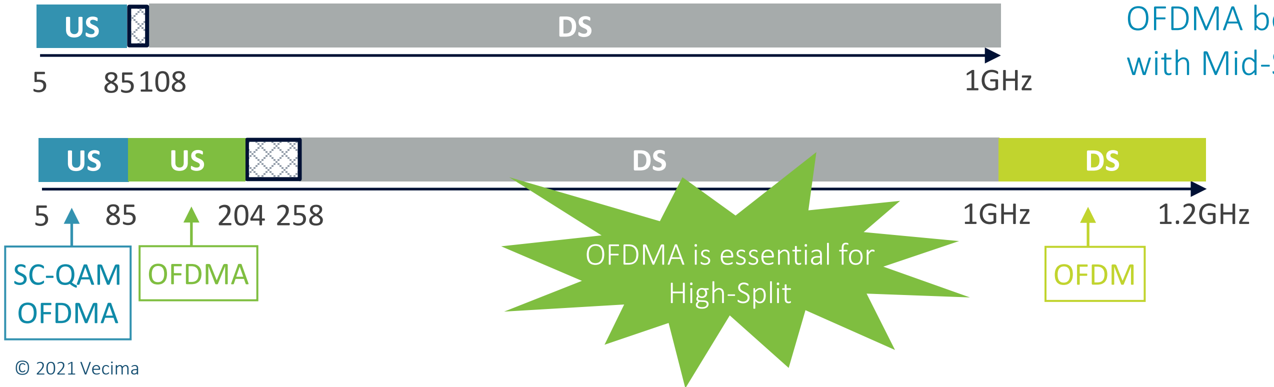
Life *without* OFDMA



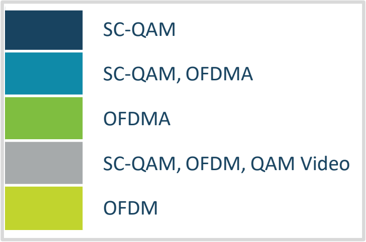
Operators moved fast to DOCSIS 3.1 OFDM downstream for 1 Gbps service.

OFDMA came late to the party due to limited spectrum.

Life *with* OFDMA



OFDMA becomes more practical with Mid-Split.



What OFDMA Brings to the Party <u>Today</u>

Full OFDMA provides nearly **~2x** upstream capacity of full SC-QAM at Mid-Split!

Low-Split and Mid-Split *without* OFDMA

US Split MHz	MHz SC-QAM	QAM Mod	US MAC Rate
42	36.8	64	**148 Mbps**
85	80	64	**325 Mbps**

Numbers show theoretical best case CMTS throughputs, assuming no upstream OOB and fully usable spectrum.

~2x upstream capacity

Mid-Split and High-Split *with* OFDMA

US Split MHz	MHz OFDMA	QAM Mod	US MAC Rate
85	80	1024	**616 Mbps**
204	192	1024 up to 108 MHz; 4096 above that	**1.62 Gbps**

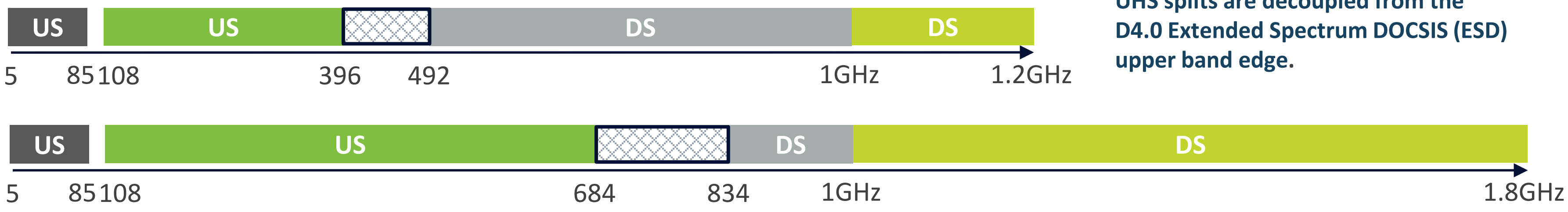
Reality is a mixture somewhere in the middle due to the need to support pre-D3.1 CMs.

What OFDMA Brings to the Party Tomorrow

Full OFDMA at 684 MHz UHS is

~40x upstream capacity of full SC-QAM best case scenario at Low-Split!

Long Term Future Based on OFDMA



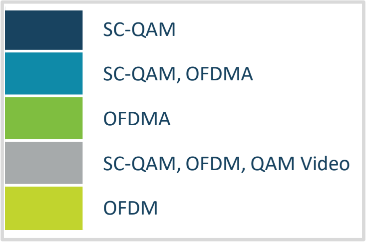
UHS splits are decoupled from the D4.0 Extended Spectrum DOCSIS (ESD) upper band edge.

DOCSIS 4.0 and Ultra High-Split (UHS)

US Split MHz	MHz OFDMA	QAM Mod	US MAC Rate
300	272	1024 up to 85MHz; 4096 above that	**2.39 Gbps**
396	368	“	**3.27 Gbps**
492	464	“	**4.16 Gbps**
684	660	“	**5.93 Gbps**

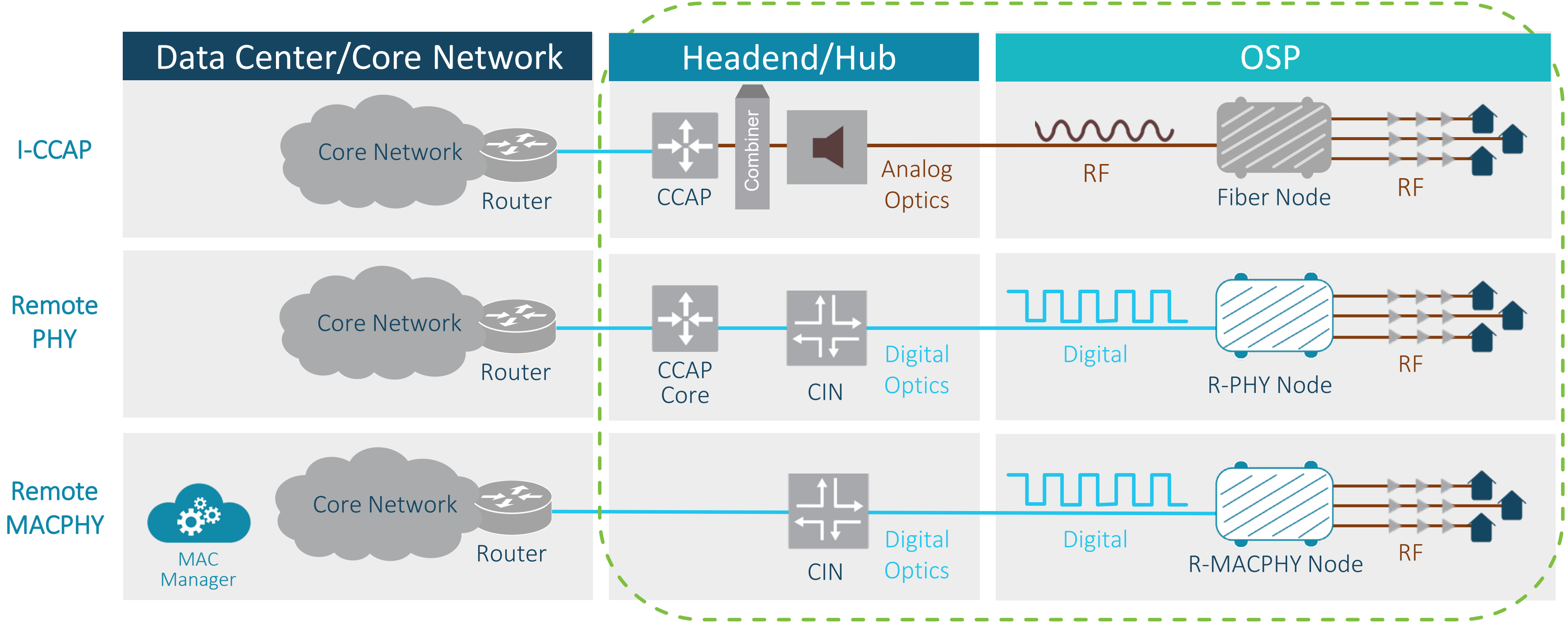
~40x upstream capacity

148 Mbps



Enter Distributed Access Architecture (DAA)

DAA moves **demod** to high performance node ADCs, improving ***overall*** upstream performance by several dB vs legacy CMTS and I-CCAP.

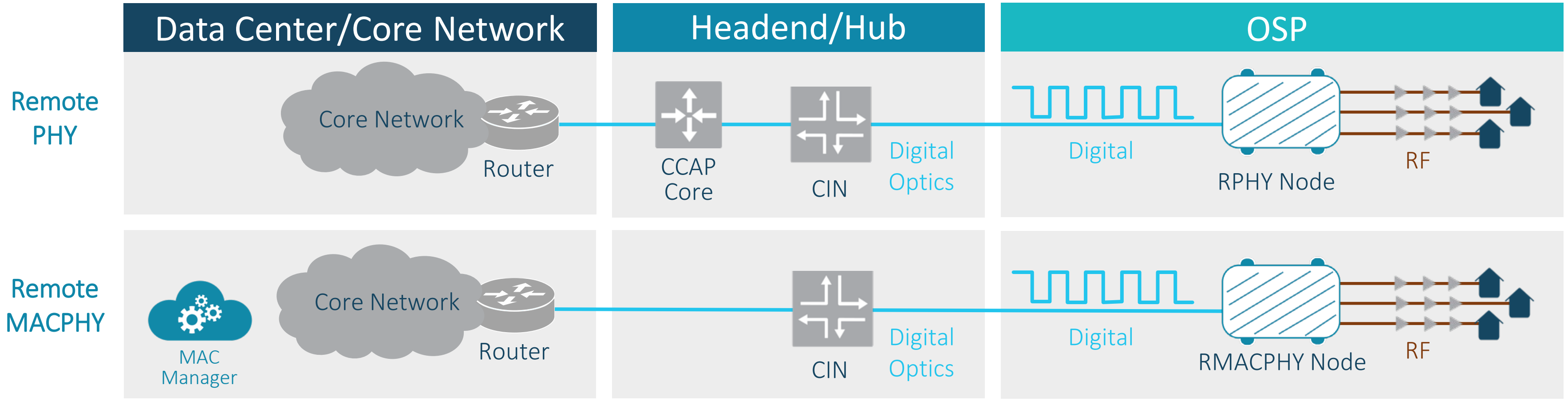


The Upstream and OFDMA Future with DOCSIS 4.0

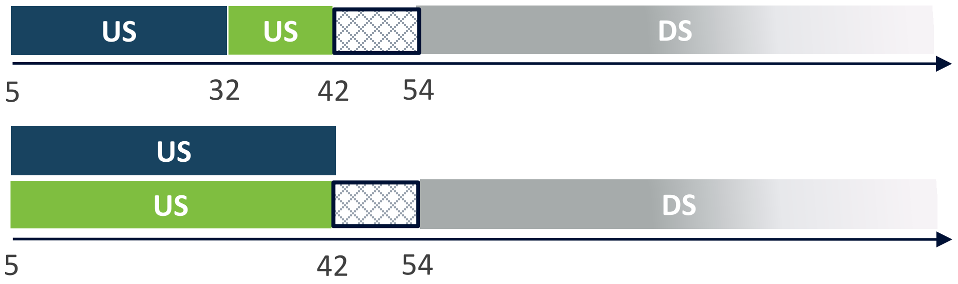
DOCSIS 4.0 UHS (300, 396, 492, 684 MHz) ***is only specified for and requires DAA.***

Operators with Low/Mid-Split that are moving to High-Split

- Is 1.2 GHz downstream and 204 MHz upstream the end game or a stopping point?
- Consider going straight to DAA in one step to reduce regrettable spend.



Migration to OFDMA – Low-Split



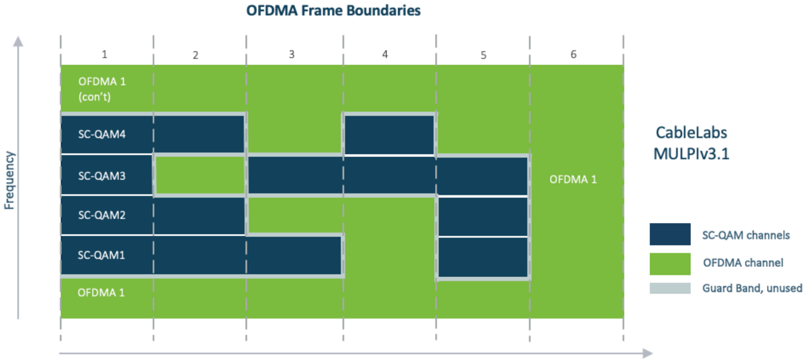
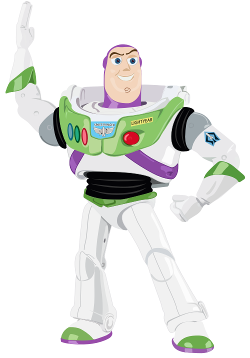


Figure 10 – Upstream Time and Frequency Multiplexing

Adding OFDMA to Low-Split.

Option	Pro	Con
Remove SC-QAM to make room for OFDMA, or put OFDMA in empty spectrum.	Preferred by field operations.	Difficult for marketing and network engineering (i.e., due to varying CM penetrations). Can force channel bonding on D3.1 CMs due to lack of spectrum; channel bonding affects LLD negatively and not bonding affects throughput.
Overlay SC-QAM with OFDMA and implement TaFDM in the overlaid spectrum.	Easy for network engineering (i.e., no need to deal with CM penetration variances). Avoids the need to channel bond D3.1 CMs	Unfamiliar to field operations. Guard bands in frequency and time can impact overall upstream throughput.

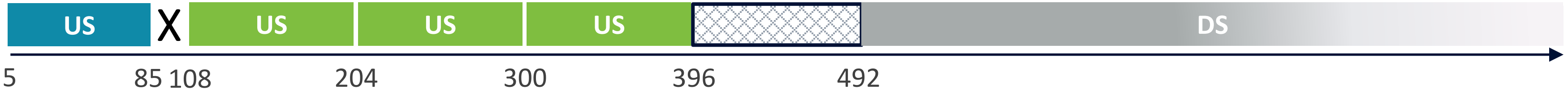
Migration to OFDMA – To High-Split and Beyond

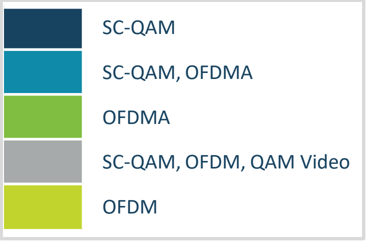


OFDMA placement in Low and Mid-Split is challenging

Operators with Low/Mid-Split that are moving to High-Split

- DOCSIS 4.0 UHS specs an N x 96 MHz channel grid anchored at 108 MHz
- High-Splits should place one OFDMA from 108 to 204 MHz
- Note: DOCSIS 4.0 CMs on a UHS plant cannot use 85 to 108 MHz





- DOCSIS 3.1 CMS on a UHS plant can use 85 to 108 MHz.
- An OFDMA channel below 108 MHz can abut the one above but cannot be used by DOCSIS 4.0 CMs

Growing Upstream with OFDMA

Throwing spectrum at the problem is an inevitable solution.

- High-Split CMTS and I-CCAP with analog forward optics, digital or analog return
- High-Split DAA with digital optics
- DOCSIS 4.0 UHS DAA with digital optics

Meanwhile, OFDMA optimization is happening in a spectrum challenged world.

- OFDMA optimization is complementary with adding spectrum
- OFDMA optimization techniques continue to develop as deployments increase
- Gains from optimizations can be multiplied across a larger number of channels as well
- Subsequent presentations in this webinar will address some practical experiences and optimizations that resulted from them

VECIMA

Once upon a time there was a place where it never rained…

The End

Jason Miller

Technical Marketing Engineer Cable Access

Cisco

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OFDMA Offers Faster Channel Rates

- OFDMA offers larger channels (up to 96 MHz) and higher order modulations compared to SC-QAM
- Just like OFDM downstreams, there are many configuration options for OFDMA upstreams compared to SC-QAM
- Some configurations can lead to large physical layer (PHY) overhead which can dramatically reduce channel speed

- Subcarrier spacing
- Pilot patterns
  (pilots / complementary pilots per minislot)
- Cyclic prefix / roll off
- Interval usage code (IUC) modulations
- Channel size / exclusion zones
- Unused subcarriers
  (400 kHz minislot roundoff)
- Symbols per frame
  (options vary with channel width and subcarrier spacing)

OFDMA Usable Channel Speed

- Usable channel speed (channel capacity minus PHY overhead)
- Channel speed = {[(total used data subcarrier per OFDMA frame x modulation order) + (total complimentary pilots per OFDMA frame x (modulation order – 4))] * (1-FEC overhead)} / OFDMA frame duration

- *Total used data subcarrier* and *total complimentary pilots* both depend on subcarrier spacing, pilot pattern, edge vs body minislot counts, and symbols per frame
- *Modulation order* depends on IUC in use
- *FEC overhead* varies with codeword size
- *OFDMA frame duration* depends on subcarrier spacing, symbols per frame, and cyclic prefix

OFDMA Usable Data Rates

DOCSIS 3.1 OFDMA speeds based on cBR-8 configuration

Note: data rate estimates in row 35 only factor out DOCSIS PHY overhead - not MAC or IP overhead

OFDMA Upstream			
FFT size (2K or 4K FFT)	2048	4096	subcarriers
Subcarrier spacing	50	25	kHz
Size of channels (MHz) - 7.4 - 96 MHz[1]	96	96	MHz
Exclusion bands (or unused bands)			MHz
Guard band on upper and lower edge (MHz)[3]	0.5	0.5	MHz
Number of active subcarriers	1900	3800	subcarriers
Cyclic prefix (Ncp)	96	96	samples[2]
Roll-off (Nrp) - must be less than Ncp	64	64	samples[2]
Ncp overhead	4.48%	2.29%	
Maximum K values based on channel size	18	9	
OFDM symbols per OFDMA Frame (K)[4]	9	9	
Minislot size (400 kHz)	8	16	subcarriers
Minislots per OFDMA frame - (minimum 25 or 16 to ASIC	237	237	
Edge minislots per OFDMA Frame (estimate)[5]	23	23	
Unused subcarriers (assumes continuous exclusion band	4	8	
OFDMA frame duration	188.44	368.44	µsec
Pilot pattern	1	8	pattern
Pilots per minislot (body)	2	2	pilots
Pilots per minislot (edge)	4	4	pilots
complementary pilots per minislot (body)	2	2	comp pilots
complementary pilots per minislot (edge)	4	4	comp pilots
Total data carriers per OFDMA frame	16024	33088	
Total complementary pilots per OFDMA frame	520	520	
Data QAM order (bits per symbol)	10	10	bits / sym
bits per minislot (body) - no FEC overhead	692	1412	bits
bits per minislot (edge) - no FEC overhead	664	1384	bits
FEC overhead (long codeword)	11.11%	11.11%	8/9 code
FEC overhead (medium codeword)	15.15%	15.15%	28/33 code
FEC overhead (short codeword)	25.00%	25.00%	3/4 code
bits per OFDMA frame	145209	296889	bits
Data Rate (Mbps)	**771**	**806**	**Mbps**
Overhead % based on active subcarriers	18.88%	15.18%	

<< formula currently assumes all long cw - 11.11% FEC overehead (bits per OFDMA frame)

Modulation Order	**Bits per Symbol**
BPSK	1
QPSK	2
8-QAM	3
16-QAM	4
32-QAM	5
64-QAM	6
128-QAM	7
256-QAM	8
512-QAM	9
1024-QAM	10
2048-QAM	11
4096-QAM	12

OFDMA frame "K" values based on encompassed spectrum (channel width - guard bands)

Minimum "K" is 6 for both 50 kHz and 25 kHz			
Maximum "K" for 50 kHz		Maximum "K" for 25 kHz	
BW >= 72 MHz	18	BW >= 72 MHz	9
48 MHz =< BW < 72 MHz	24	48 MHz =< BW < 72 MHz	12
BW < 48 MHz	36	BW < 48 MHz	18

[1] Valid channel sizes 11 - 96 MHz for 50 kHz; 7.4 - 96 MHz 25 kHz (includes 0.5 MHz guard band per edge)

[2] sampling rate is 102.4 MHz (based on OFDM spectrum - FFT size x subcarrier width)

[3] Note that guard bands are fixed at 0.5 MHz on cBR-8

[4] K values must fall in range from table on right

[5] Edge minislots occur at start of OFDMA frame, after exluded or unused spectrum, and at start of modem burst (10% might be a good estimate - has minimal impact on estimate)

Typical to get 97% of data rate in lab testing (~3% MAC overhead)

Spread sheet available in green resource widget section

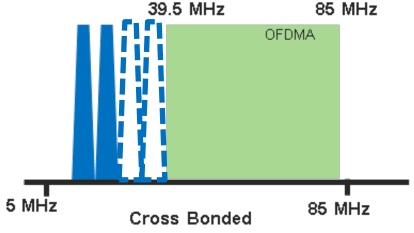
OFDMA Field Optimization Process

- Configure OFDMA channel to run as fast as possible by minimizing PHY overhead and providing multiple modulation order options
- Increase PHY overhead as required to reduce any undesirable events like uncorrectable codeword errors (cw errors)
- Monitor RxMER values per subcarrier
- Balance PHY overhead with channel speed (increased overhead may be desired if it improves RxMER to allow higher order modulations)

High and stable RxMER values lead to high order modulations

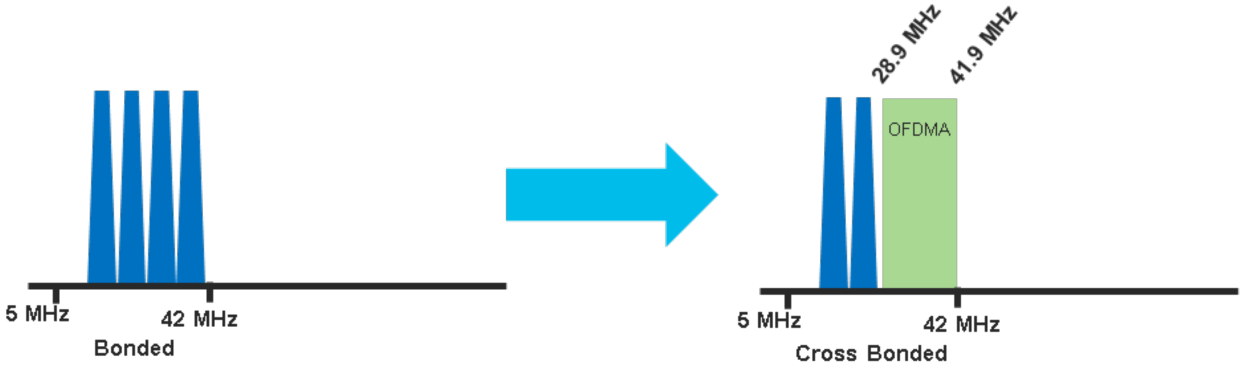
Midco OFDMA Field Trial 2017

- Field trial in markets with 85 MHz HFC plant
- 2 x 6.4 MHz SC-QAM + 44.5 MHz OFDMA
- 6.4 MHz SC-QAM @ 64-QAM ~ 25 Mbps
- 45.5 MHz OFDMA @ 1024-QAM ~ 365 Mbps
- Total US for D3.1 modem cross bonding ~ 415 Mbps
- Clean plant with no issues doing 1024-QAM modulations (highest supported at time in software) with minimized PHY overhead
- With 4 x 6.4 MHz SC-QAM + 44.5 MHz OFDMA would expect cross bonding capacity of ~ 465 Mbps



Blue Ridge Cable OFDMA Deployment 2019

- Limited upstream spectrum with 42 MHz HFC plant
- Reduced from 4 x SC-QAM to 2 x SC-QAM to add OFDMA
- 4 x 6.4 MHz SC-QAM ~ 100 Mbps
- 13 MHz OFDMA @ 1024-QAM ~ 100 Mbps
- 2 x 6.4 MHz SC-QAM + 13 MHz OFDMA ~ 150 Mbps
- Postpone plant changes (85 MHz, 204 MHz, RPHY, FDX, FDD)

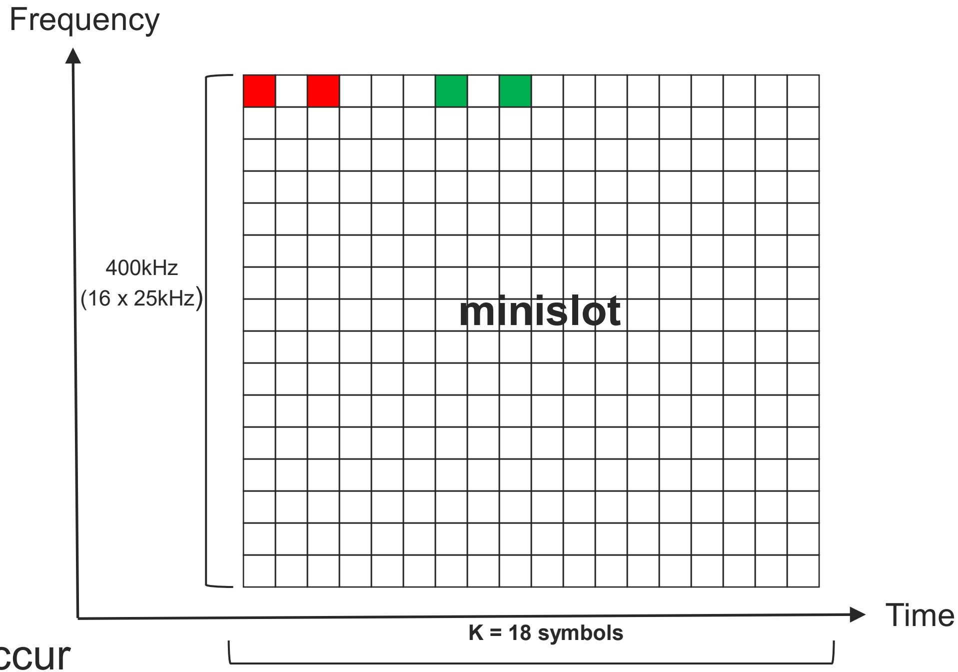


Blue Ridge D3.1 Modem Deployments

- Approximately 1/3 of modems deployed are D3.1
- Assured users running top two speed tiers in test areas were using D3.1 modems
  - 1 Gbps x 40 Mbps (3% of users)
  - 500 Mbps x 25 Mbps (4% of users)
  - Remaining users do ≥ 15 Mbps on upstream
- 4 SC-QAM were not fully utilized before test
- No impact on D3.0 modems after halving original 100 Mbps of available US capacity (now only 2 x 6.4 MHz SC-QAM)

Initial OFDMA Configuration

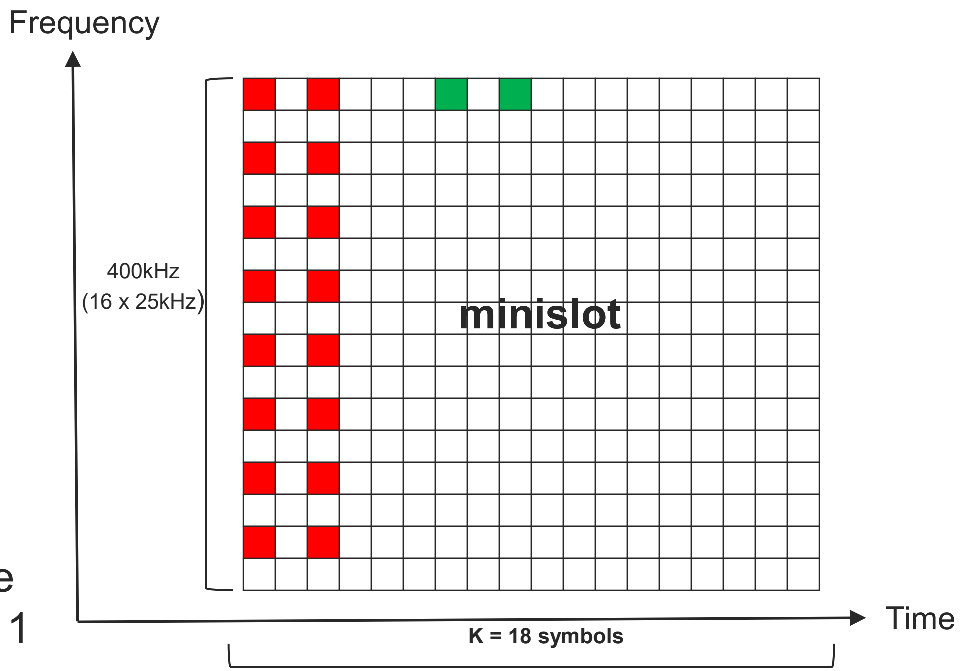
```
cable mod-profile-ofdma 428
  subcarrier-spacing 25KHz
  initial-rng-subcarrier 64
  fine-rng-subcarrier 128
  data-iuc 9 modulation 1024-QAM pilot-pattern 8
  data-iuc 10 modulation 512-QAM pilot-pattern 8
  data-iuc 10 modulation 256-QAM pilot-pattern 8
  data-iuc 11 modulation 128-QAM pilot-pattern 8
  data-iuc 12 modulation 64-QAM pilot-pattern 8
  data-iuc 13 modulation 16-QAM pilot-pattern 8

 us-channel 12 docsis-mode ofdma
 us-channel 12 subcarrier-spacing 25KHz
 us-channel 12 modulation-profile 428
 us-channel 12 frequency-range 28900000 41900000
 us-channel 12 cyclic-prefix 96 roll-off-period 64
 us-channel 12 symbols-per-frame 18
 no us-channel 12 shutdown
```



- OFDMA channel ~ 100 Mbps (1024-QAM)
- Occasional uncorrected cw errors would occur at 1024-QAM and 512-QAM
- Limited maximum modulation to 256-QAM initially (~ 80 Mbps)

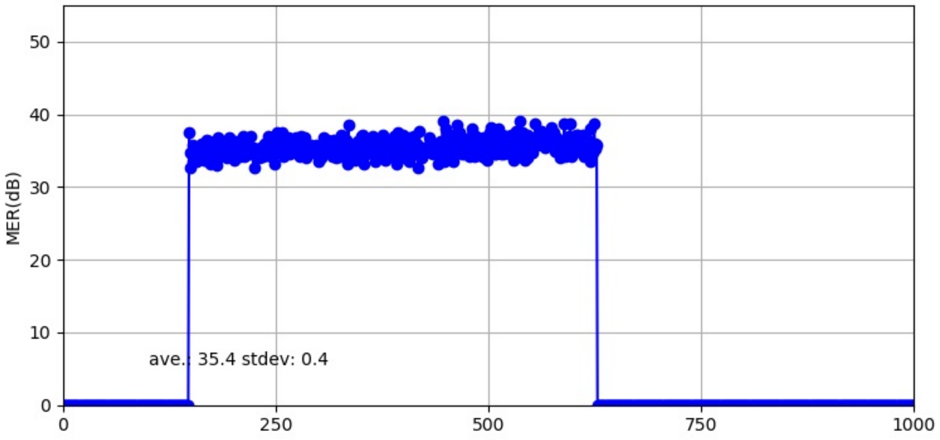
Updated OFDMA Configuration

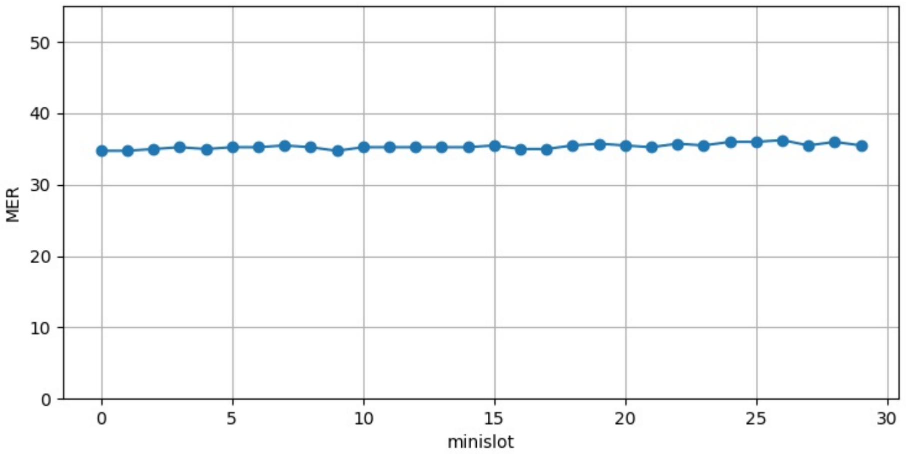
```
cable mod-profile-ofdma 450
  subcarrier-spacing 25KHz
  initial-rng-subcarrier 64
  fine-rng-subcarrier 128
  data-iuc 9 modulation 1024-QAM pilot-pattern 11
  data-iuc 10 modulation 512-QAM pilot-pattern 11
  data-iuc 11 modulation 256-QAM pilot-pattern 11
  data-iuc 12 modulation 128-QAM pilot-pattern 11
  data-iuc 13 modulation 64-QAM pilot-pattern 11

 us-channel 12 docsis-mode ofdma
 us-channel 12 subcarrier-spacing 25KHz
 us-channel 12 modulation-profile 450
 us-channel 12 frequency-range 28900000 41900000
 us-channel 12 cyclic-prefix 96 roll-off-period 64
 us-channel 12 symbols-per-frame 18
 no us-channel 12 shutdown
```



- Adjusted cyclic prefix / roll off but no change
- Increased pilot overhead with pilot pattern 11 verse pilot pattern 8
- OFDMA channel ~ 95 Mbps (~5% speed reduction based on 1024-QAM)
- Dribble of uncorrected cw errors stopped

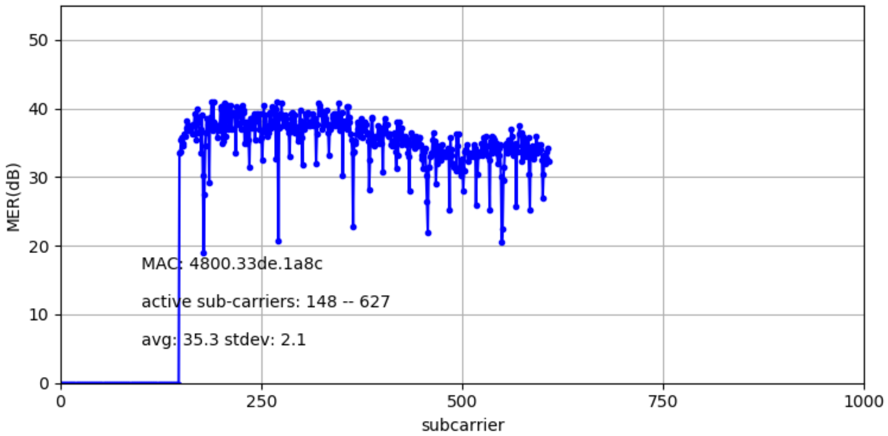
Modem RxMER At Node + 9 Actives

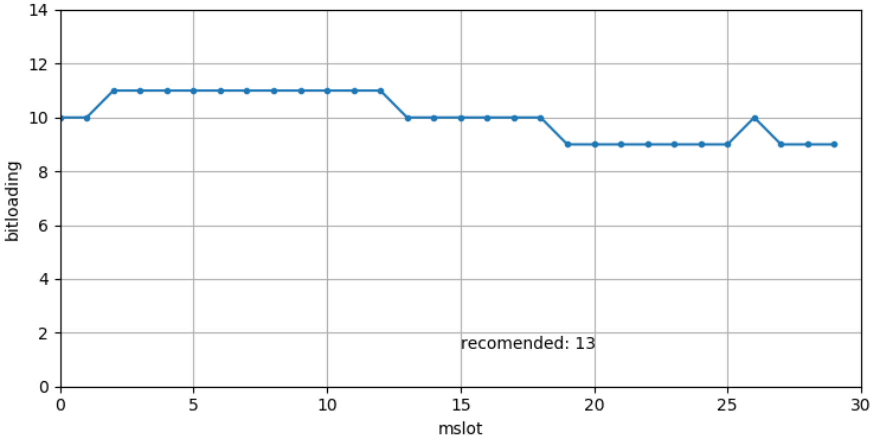




- Modem transmits error free at 1024-QAM
- RxMER readings similar between Broadcom and Intel based modems
- Pre-equalization noticeably increased RxMER near high band edge

Nodes Experience Impairments In Upstream





- More transient impairments on upstream plant compared to downstream
- Enable features to downgrade IUCs based on cw errors or move to partial service if cw errors on IUC 13
- Can also move to partial service based on RxMER if unable to run on IUC 13 (detect filters when running OFDMA above 42 MHz)

OFDMA Configuration Recommendations

- 25 kHz subcarrier spacing recommended over 50 kHz (less overhead - although minimal with low cyclic prefix values)
- Cyclic prefix seems to have minimal impact on RxMER for OFDMA channel so run as low as possible to minimize overhead
- Pilot patterns with more overhead have been effective in reducing periodic cw errors
- IUC 13 should be robust enough for all modems to use error free (64-QAM or 16-QAM) – may need IUC override if in poor spectrum (< 10 MHz)
- Add multiple IUCs with higher modulation orders so modems can transmit at higher speeds
- Avoid noisy spectrum below 10 MHz (minimal capacity gains)

Robert Flask

Head of Product Line Management

Cable & Access Instrument Solutions

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OFDM-A and the Path to 1 Gbps

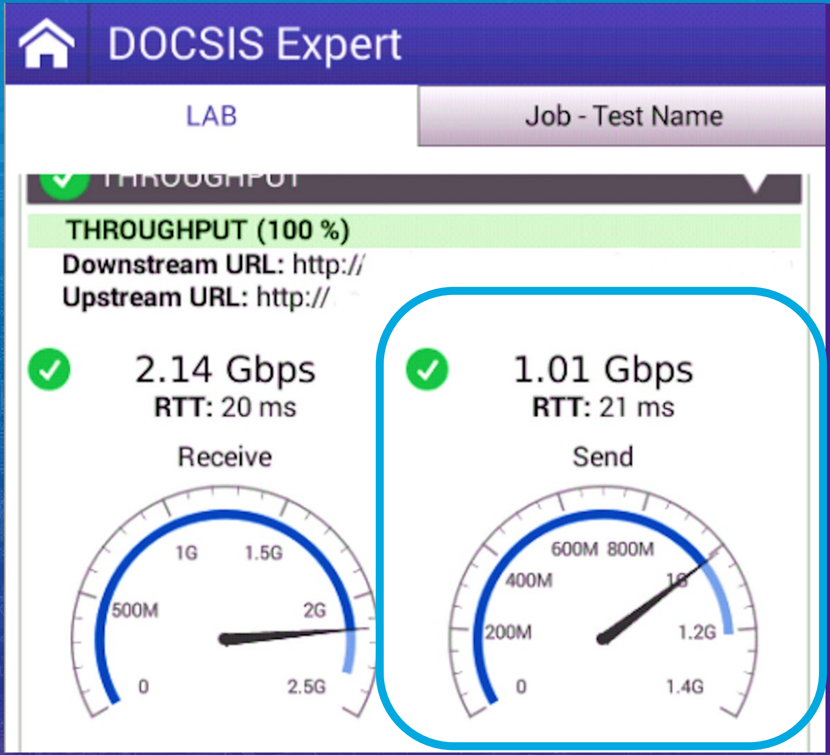
Simplify Network Transitions to Meet US demand

Speaker Name: Robert J. Flask

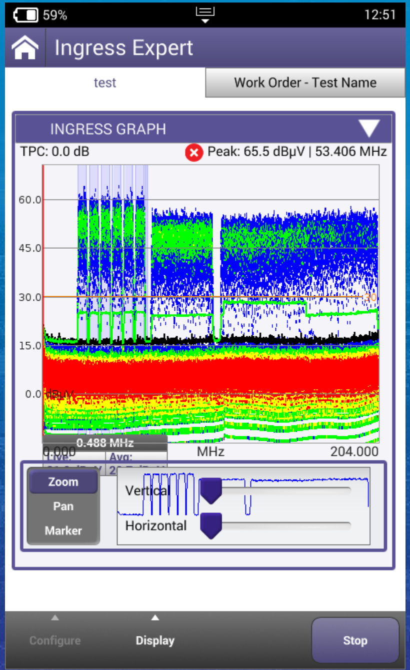
Speaker Title: Sr. Product Line Manager

Date: February 18, 2021

OFDM-A and 204 MHz Provides >1 Gpbs Upstream



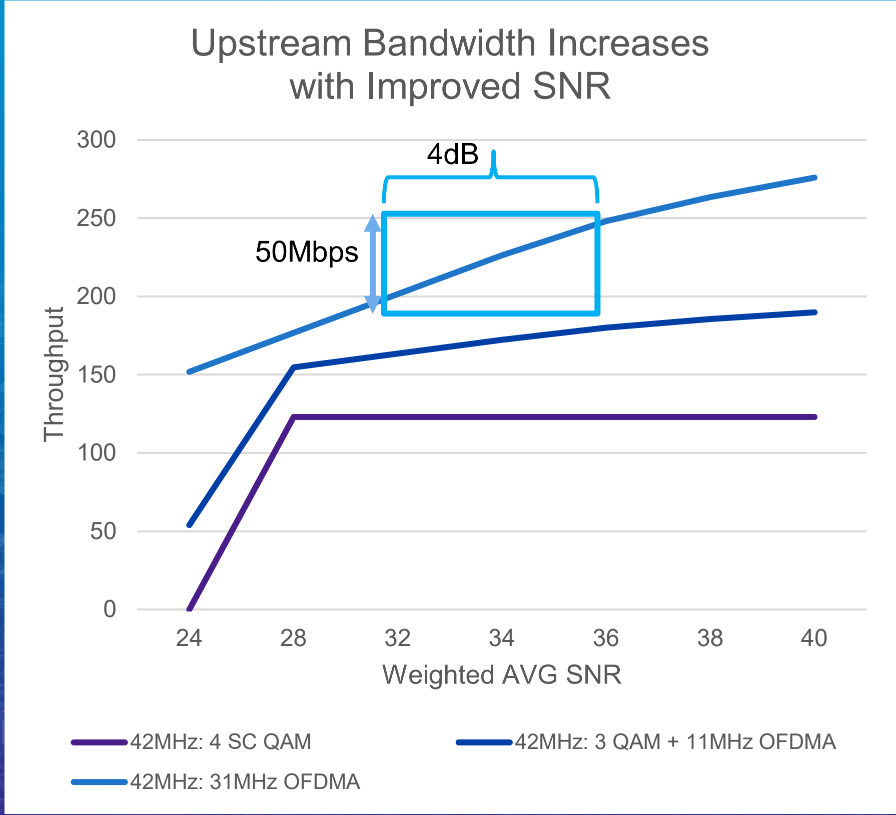
Operators can add OFDM-A in new spectrum to get to 1 Gbps while keeping SC-QAM's for DOCSIS 3.0 users



The BETTER and CLEANER the Plant – the Faster it Goes

SNR	Bits/Hz	42 MHz Low Split 4 SC QAM	42 MHz Low Split 3 SC QAM + 11MHz OFDMA	42 MHz Low Split 31 MHz OFDMA
24	4.9	0 Mbps	54 Mbps	152 Mbps
28	5.7	123 Mbps	155 Mbps	177 Mbps
32	6.5	123 Mbps	165 Mbps	200 Mbps
34	7.3	123 Mbps	172 Mbps	226 Mbps
36	8.0	123 Mbps	180 Mbps	250 Mbps
38	8.5	123 Mbps	186 Mbps	265 Mbps
40	8.9	123 Mbps	190 Mbps	275 Mbps

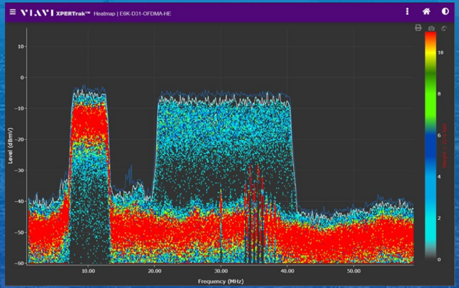
- With OFDM-A every **dB = $$$**
- With OFDM-A In a 42MHz plant a **4dB improvement can add >50Mbps!!**
- That is more bandwidth than adding an SC-QAM
- The bandwidth gains of going to OFDM-A are dependent on the SNR of the modem population and using profiles



Best Practices for Plant Clean Up and Preparation

Recommendations

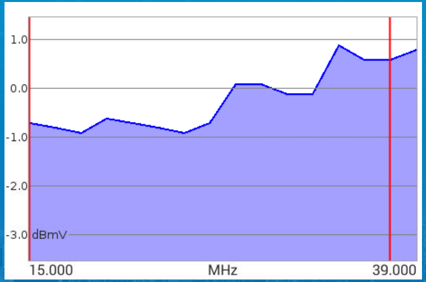
Ingress Monitoring with QOE and Localization	Drive Out Leakage to Pinpoint and Fix Problems	Ingress Testing at Every Home	Wiring integrity testing at every home with High Level Pressure/Leakage testing



OFDM-A Field Operations – Return Sweep

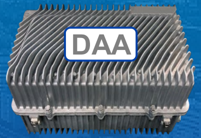
Recommendations

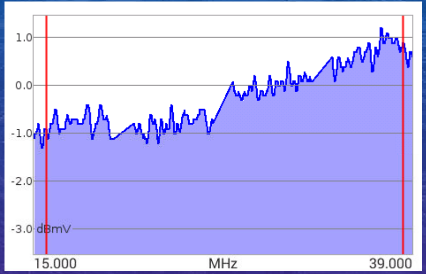
- Set up sweep points for fast alignment and troubleshooting
- Use next gen advanced reverse sweep technology to allow sweep point injection through OFDM-A carriers without degradation
- Use Reverse Sweepless Sweep using the upstream carriers to view detailed frequency response of the OFDM-A carrier and compare, align and troubleshoot



STEALTH SWEEP CARRIERS:

- Faster updates
- Always works – reliable
- Align/Balance
- Outage Troubleshooting





REVERSE SWEEPLESS:

- No HE/Hub HW, Server
- Higher resolution
- Auto-configs to changes
- Freq response checks

Wrap-Up

- OFDM-A isn't a lab experiment". It is real and it is providing over 1Gbps upstream in high split system
- Cleaning up your plant is imperative to get the most out of OFDM-A. dB=$$$
- Using advanced modulations can increase capacity even in low and mid-split systems. It is like adding carriers for free.
- Existing tools with heatmap and monitoring can help plan, deploy and troubleshoot OFDM-A

VIAVI Solutions

viavisolutions.com

Rob Wilmoth

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DOCSIS and Software Defined Architectures

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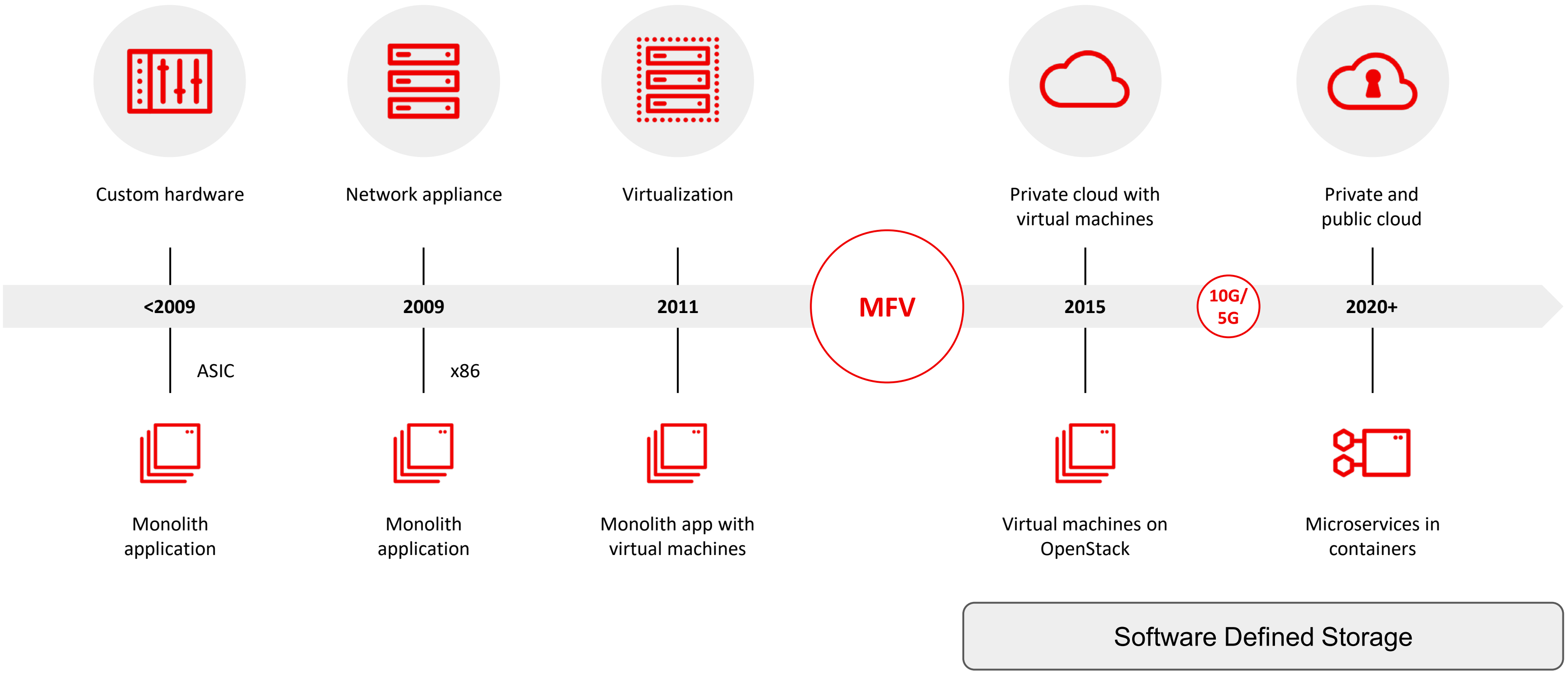
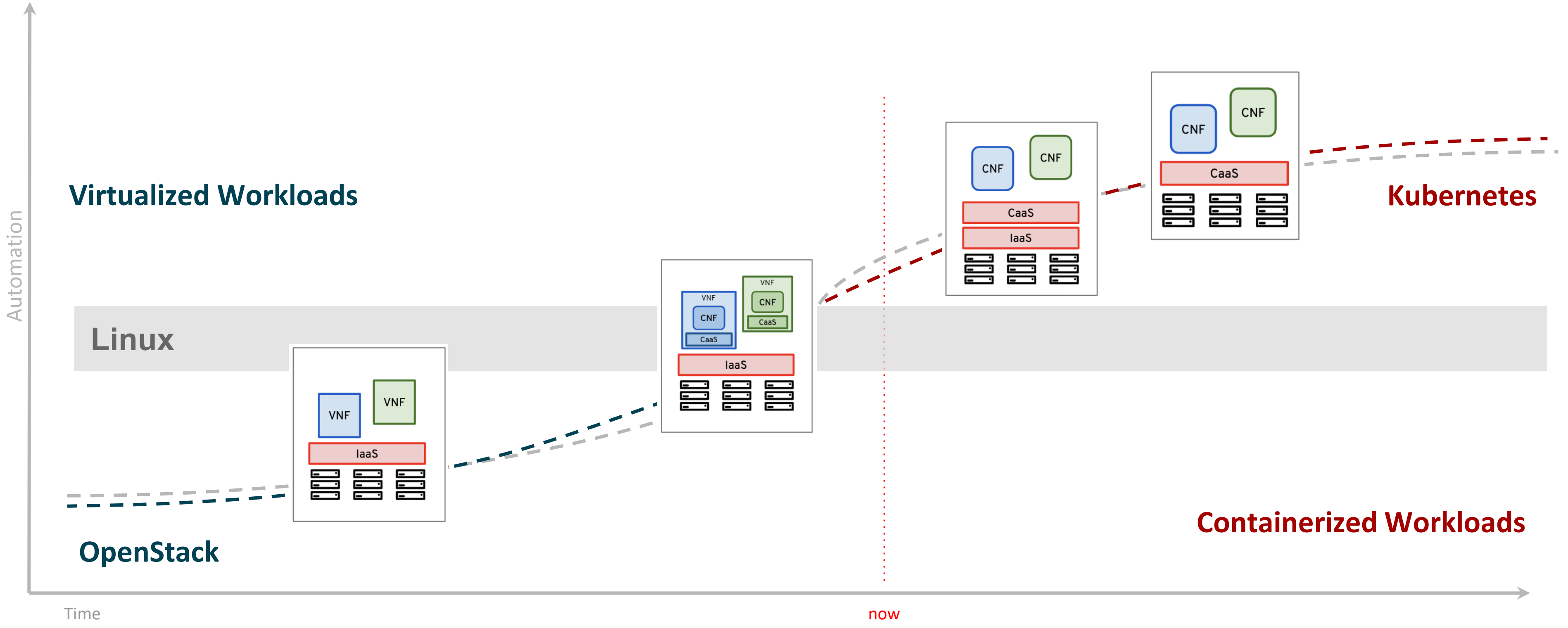
Red Hat

NFV Journey


Custom hardware
Network appliance
Virtualization
Private cloud with virtual machines
Private and public cloud
<2009
2009
2011
MFV
2015
10G/ 5G
2020+
ASIC
x86
Monolith application
Monolith application
Monolith app with virtual machines
Virtual machines on OpenStack
Microservices in containers
Software Defined Storage

Media Cloud Evolution to Cloud Native



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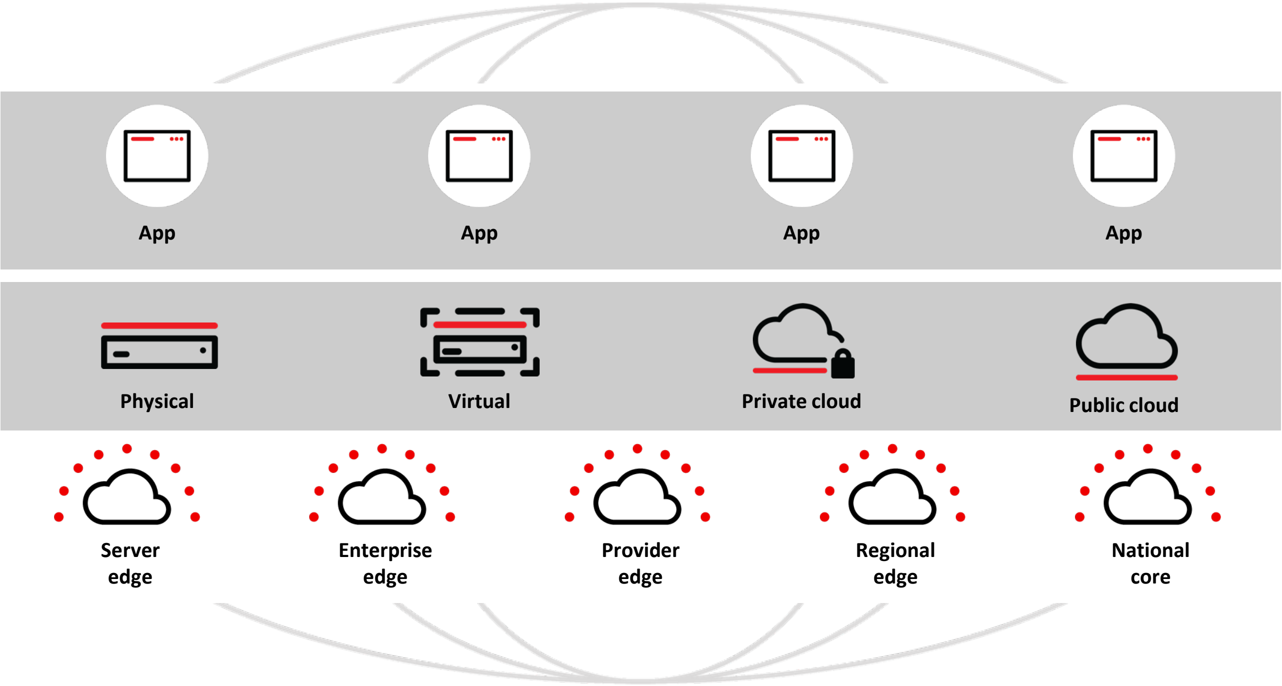
The Open Hybrid Cloud now extends to the Edge

Any workload, any footprint, **any location**.



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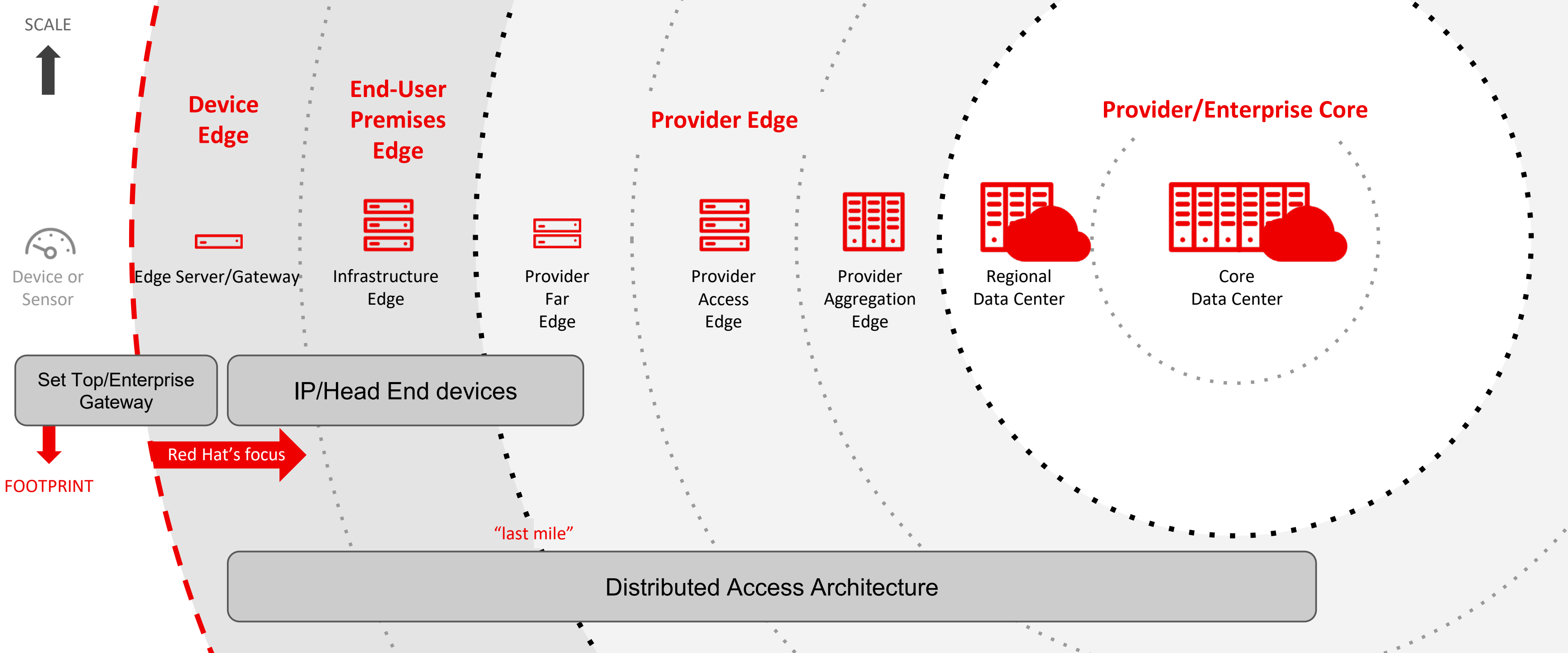
Edge Tiers

Centralize where you can, distribute where you must.



Who is doing Edge Computing

Enterprise	Service Provider	Public sector	Artificial intelligence/ Machine learning	Internet of Things
(Retail) Remote office	Radio Access Network (vRAN)	Connected sensors and controllers	Video surveillance	Trading sensitive apps
In-field operations	Multi access edge computing	Universal customer premise equipment	Connected car, train, plane	Healthcare monitoring and data processing
and more...	Private 5G	and more...	and more...	and more...
	and more...			

Digital service provider landscape

Network ⟷ IT

Fixed access

Radio access

VNFs and CNFs[1]

Media CDN[2]

Mobile broadband[3]

Enterprise services

Operations support systems (OSS)

- Network inventory
- Service provisioning
- Network configuration
- Service assurance

Business support systems (BSS)

- Product management
- Order management
- Revenue management
- Customer management

Network infrastructure

- Edge cloud
- Regional cloud
- Private cloud
- Public cloud

IT infrastructure

- Private cloud
- Public cloud

NOTES:
1 Virtual network functions and containerized network functions
2 Content delivery network
3 Including 5G core

Red Hat

Steve Harris

Executive Director, Technical Sales, Learning & Development SCTE|ISBE

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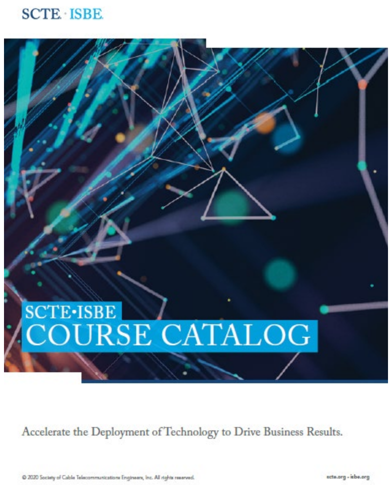

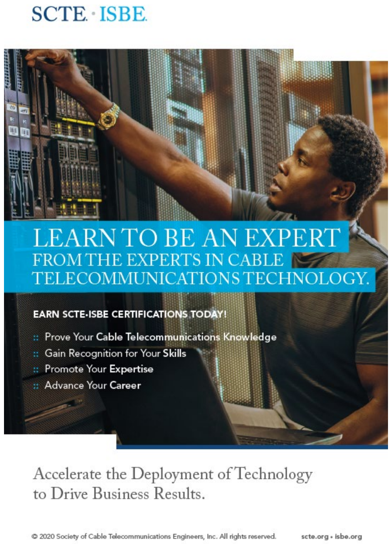

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Audience Q & A

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VIAVI Solutions

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Chief Architect Service Provider Team
Red Hat North America

Next Month's Webinar

What's New with DAA & Flexible MAC

3/18/2021 11:00 am New York / 4:00 pm London

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Audience Poll I

If something goes wrong when consumers are watching streaming video, who do they tend to blame?

- Network service provider
- Content provider (e.g. YouTube)
- Home Wi-Fi connection
- App they are using to watch it
- Viewing device (TV, tablet, handset, etc.)
- Bad karma

Audience Poll II

How much of a viewer's video QoE is actually under the video provider's control?

- All of it
- Most of it
- About half
- Not that much
- None of it